



# TIAPS “Through the Sensor Probing” Technique

*C. Calnan*  
*xwave*

*xwave*  
*36 Solutions Drive*  
*Halifax, NS B3S 1N2*

*Project Manager: J. Theriault, 902-426-3100 x376*

*Contract Number: W7707-04-2580*

*Contract Scientific Authority: J. Theriault, 902-426-3100 x376*

*xwave Contract Number: 1008554 SENSOR PROBE*

## Defence R&D Canada – Atlantic

Contract Report  
DRDC Atlantic CR 2005-033  
March 2005

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>MAR 2005</b>		2. REPORT TYPE		3. DATES COVERED -	
4. TITLE AND SUBTITLE <b>TIAPS Through th eSensing Probing Technique</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Defence R&amp;D Canada -Atlantic,PO Box 1012,Dartmouth, Nova Scotia,CA,B2Y 3Z7</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>The original document contains color images.</b>					
14. ABSTRACT <b>An earlier contract (Calnan [2004]) resulted in the creation of BREVER, a program able to perform reverberation inversion on processed ping data from TIAPS sea trials. The inversion results, which are the geoacoustical properties of the pings' environments, could be used to calculate transmission losses in these environments. This contract was let to perform inversions on a number of pings, calculate transmission losses, and compare the results to those obtained from other means. This contract was also intended to permit enhancement of the reverberation program and assist the Scientific Authority in the preparation of a conference presentation and paper. As it happened the processed pings did not become available during the course of the contract, thus preventing the inversion and transmission loss comparisons. However the other work was performed, and a number of other tasks related to BREVER and its analysis engine, SWAMI, were performed. These included verifying the consistency and accuracy of inversion results, enhancing the operation of BREVER, and performing some initial work to SWAMI that would allow the use of the program Bellhop, which produces eigenray-based environments, to replace the normal mode program PMODES.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES <b>52</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

This page intentionally left blank.

# **TIAPS “Through the Sensor Probing” Technique**

C. Calnan  
xwave

xwave  
36 Solutions Drive  
Halifax, NS B3S 1N2

Project Manager: J. Theriault 902-426-3100 ext 376

Contract Number: W7707-04-2580

Contract Scientific Authority: J. Theriault 902-426-3100 ext 376

xwave Contract Number: 1008554 SENSOR PROBE

## **Defence R&D Canada – Atlantic**

Contract Report

DRDC Atlantic CR 2005-033

March 2005

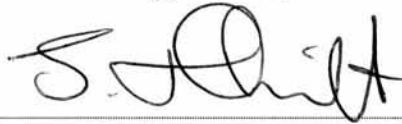
Author



---

C. Calnan

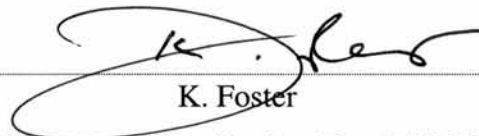
Approved by



---

J. Theriault  
Contract Scientific Authority

Approved for release by



---

K. Foster  
Chair, Document Review Panel (DRP)

**Terms of release:** The scientific or technical validity of this Contract Report is entirely the responsibility of the contractor and the contents do not necessarily have the approval or endorsement of Defence R&D Canada.

**Terms of release:** The information contained herein is proprietary to Her Majesty and is provided to the recipient on the understanding that it will be used for information and evaluation purposes only. Any commercial use including use for manufacture is prohibited. Release to third parties of this publication or information contained herein is prohibited without the prior written consent of Defence R&D Canada.

© Her Majesty the Queen as represented by the Minister of National Defence, 2005

© Sa majesté la reine, représentée par le ministre de la Défense nationale, 2005

IDL® is a registered trademark of Research Systems Incorporated

## Abstract

---

An earlier contract (Calnan [2004]) resulted in the creation of **BREVER**, a program able to perform reverberation inversion on processed ping data from TIAPS sea trials. The inversion results, which are the geoacoustical properties of the pings' environments, could be used to calculate transmission losses in these environments.

This contract was let to perform inversions on a number of pings, calculate transmission losses, and compare the results to those obtained from other means. This contract was also intended to permit enhancement of the reverberation program and assist the Scientific Authority in the preparation of a conference presentation and paper.

As it happened the processed pings did not become available during the course of the contract, thus preventing the inversion and transmission loss comparisons. However the other work was performed, and a number of other tasks related to **BREVER** and its analysis engine, SWAMI, were performed. These included verifying the consistency and accuracy of inversion results, enhancing the operation of **BREVER**, and performing some initial work to SWAMI that would allow the use of the program **Bellhop**, which produces eigenray-based environments, to replace the normal mode program **PMODES**.

## Résumé

---

Un contrat antérieur (Calnan [2004]) a mené à la création du programme **BREVER**, capable d'exécuter une inversion de réverbération des données d'impulsions traitées provenant des essais en mer du sonar actif-passif intégré remorqué (TIAPS). Les résultats de l'inversion, qui correspondent aux propriétés géoacoustiques des environnements des impulsions, pourraient servir à calculer les pertes de transmission dans ces environnements.

Ce contrat portait sur l'exécution d'inversions pour un certain nombre d'impulsions, le calcul des pertes de transmission et la comparaison des résultats avec ceux obtenus par d'autres moyens. Il visait aussi à permettre l'amélioration du programme de réverbération et à soutenir l'autorité scientifique dans la préparation d'une présentation à une conférence ainsi que d'un document écrit.

Il se trouve que les impulsions traitées n'ont pas été disponibles durant le contrat, ce qui a empêché les comparaisons d'inversion et de perte de transmission. Les autres travaux ont toutefois effectivement eu lieu, de même qu'un certain nombre de tâches relatives à **BREVER** et à son moteur d'analyse, SWAMI. Ces tâches comprenaient la vérification de l'uniformité et de la précision des résultats de l'inversion, l'amélioration du fonctionnement de **BREVER** et l'exécution de certains travaux initiaux touchant SWAMI qui permettraient l'utilisation du programme **Bellhop**, générateur d'environnements à vecteurs propres, en remplacement du programme **PMODES** de mode normal.

This page intentionally left blank.

# Executive Summary

---

## Introduction

An earlier contract resulted in the creation of **BREVER**, a program able to perform reverberation inversion on processed ping data from TIAPS sea trials. The inversion results, which are the geoacoustical properties of the acoustic environment, could be used to calculate transmission losses in these environments.

## Results

This contracted effort was to perform inversions on a number of pings, calculate transmission losses, and compare the results to those obtained from other means, as well as to permit enhancement of the reverberation program and assist the Scientific Authority in the preparation of a conference presentation and paper.

The enhancements to the reverberation model and the support for the conference presentation and paper consumed all of the resources. Nevertheless, the technique was shown to be a theoretically viable approach to inferring geoacoustic parameters

## Significance

This effort lends itself to two particular applications. The first is Rapid Environmental Assessment (REA) using “through-the-sensor” techniques. The methodology extracts geoacoustic parameters from reverberation time series, one of the many goals of REA. The second application is in the development of Tactical Decision Aids (TDA). Real-time sonar performance estimation using in-situ measurements would provide the sonar operator with the capability to better employ the sensor.

## Future plans

An effort to invert reverberation data measured by DRDC Atlantic’s Towed Integrated Active-Passive Sonar (TIAPS) is underway. Future effort will be to produce estimates of geoacoustic parameters and compare with independent measurements. A further extension is to use a SWAMI component to predict transmission loss to compare with independently measured transmission loss in the area.

Calnan, C. 2005. *TIAPS “Through the Sensor Probing” Technique*, DRDC Atlantic CR 2005-033. Defence R&D Canada – Atlantic.



# Sommaire

---

## Introduction

Un contrat antérieur a mené à la création du programme **BREVER**, capable d'exécuter une inversion de réverbération des données d'impulsions traitées provenant des essais en mer du sonar actif-passif intégré remorqué (TIAPS). Les résultats de l'inversion, qui correspondent aux propriétés géoacoustiques de l'environnement acoustique, pourraient servir à calculer les pertes de transmission dans ces environnements.

## Résultats

Ce contrat portait sur l'exécution d'inversions pour un certain nombre d'impulsions, le calcul des pertes de transmission et la comparaison des résultats avec ceux obtenus par d'autres moyens, et il visait aussi à permettre l'amélioration du programme de réverbération et à soutenir l'autorité scientifique dans la préparation d'une présentation à une conférence ainsi que d'un document écrit.

Les améliorations du modèle de réverbération ainsi que le soutien pour la préparation de la présentation et du document ont monopolisé toutes les ressources. Néanmoins, il s'est avéré que la technique était théoriquement viable pour l'inférence de paramètres géoacoustiques.

## Portée

Cette initiative se prête à deux applications particulières. La première est l'analyse environnementale rapide (REA) selon des techniques de détection par capteurs. Ces techniques permettent d'extraire des paramètres géoacoustiques à partir de séries chronologiques de réverbération, ce qui constitue l'un des nombreux objectifs de la REA. La deuxième application a trait au développement d'aides à la prise de décisions tactiques (TDA). Les évaluations en temps réel des performances du sonar à partir de mesures sur place permettraient à l'opérateur du sonar de mieux employer sa capacité de détection.

## Recherches futures

Des travaux portent actuellement sur l'inversion des données de réverbération obtenues par le sonar actif-passif intégré remorqué (TIAPS) de RDDC Atlantique. Des recherches futures viseront à évaluer les paramètres géoacoustiques et à les comparer avec des mesures indépendantes. On utilisera également la composante SWAMI pour prévoir les pertes de transmission et établir une comparaison avec les pertes de transmission mesurées indépendamment dans la région.

Calnan, C. 2005. *TIAPS "Through the Sensor Probing" Technique* DRDC Atlantic CR 2005-033. Defence R&D Canada – Atlantic.

# Table of Contents

---

Abstract.....	i
Résumé .....	i
Executive Summary.....	iii
Sommaire.....	iv
Table of Contents .....	v
List of Tables.....	vii
List of File Listings .....	viii
List of Figures.....	ix
1. Introduction .....	1
2. SWAMI Directional Sensor Implementation .....	4
3. Conference Presentation/Scientific Paper .....	5
4. Reverberation Inversion Results Statistics .....	6
5. SWAMI Timing Tests .....	11
6. Changes to <b>BREVER</b> Input .....	13
6.1 Data Line 6: Points per Radial.....	13
6.2 Data Line 20: Measured Data File.....	14
7. Eigenray Input for <b>MONOGO</b> .....	16
7.1 Introduction .....	16
7.2 <b>MONOGO</b> Input .....	16
7.3 <b>MONOGO</b> Changes.....	17
7.4 <b>MONOGO</b> Expansion Status.....	18
7.5 <b>Bellhop</b> Modification.....	19
7.6 <b>BREVER</b> Eigenray Expansion .....	19

8.	SWAMI Eigenray File Format .....	20
9.	<b>BREVER</b> Water Depths .....	23
10.	<b>BREVER</b> Test Results.....	24
11.	File Locations .....	29
12.	Suggestions for Further Work .....	30
	Bibliography .....	32
	Initialisms and Acronyms .....	33
	Distribution List.....	34

## List of Tables

---

Table 1. Distribution of Standard Deviation Percentages.....	10
Table 2. SWAMI Timing Runs .....	11
Table 3. Points/Radial Options.....	14
Table 4. Proposed <b>Bellhop</b> Eigenray File Header .....	21
Table 5. Proposed <b>Bellhop</b> Eigenray File Data Layout .....	22
Table 6. <b>BREVER</b> Results v. Original Data.....	27

## List of File Listings

---

Listing 1. Reverberation Inversion Statistics.....	7
--	---

## List of Figures

---

Figure 1. Reverberation Delta Time Series .....	24
Figure 2. Reverberation Delta Differences: Results minus Measured.....	25
Figure 3. Reverberation Time Series.....	26
Figure 4. Reverberation Differences: Results minus Measured .....	26

This page intentionally left blank.

# 1. Introduction

---

The current contract was let in part to continue the work performed for a contract described in Calnan [2004]. That project resulted in the creation of the IDL program **BREVER**, which performs reverberation inversion using an Adaptive Simulated Simplex Annealing (ASSA) technique. The inversion's results determine the geoacoustical parameters that produce a reverberation time series whose slope best fits that of observed reverberation time series recorded on various TIAPS sea trials.

During a **BREVER** run the model SWAMI (Shallow Water Active-sonar Modelling Initiative) uses test geoacoustical parameters to iteratively produce a reverberation time series that is compared to the observed time series. Over a number of runs the modelled time series eventually converges with the observed data. The parameters that produced the "best fit" time series are assumed to be close to the actual parameter values and so are presented as the inversion's results.

**BREVER** itself, however, is just the inversion "framework" and only sets up test parameters and runs the programs that perform the calculations required to produce test reverberation time series. The programs that perform the required calculations are components of the SWAMI reverberation model. The SWAMI components have been made to run on Linux by way of the GNU FORTRAN 77 compiler **g77**.

Besides creating **BREVER**, the earlier project was intended to perform some real world analysis using processed reverberation data. However data processing errors corrupted the data to be processed and so no data were available for inversion. Part of the requirements of the current contract was to perform the inversions, under the assumption that the reverberation time series data would be ready for analysis.

The full list of tasks set out for this contract is:

## Task 1

Enhance the SWAMI code so it can perform calculations for arrays of directional sensors, such as the Directional Acoustic Sensor Module (DASM). At present the code will only perform calculations for receiving arrays of omni-directional sensors.

This task was the first one performed and is discussed in Section 2.

## Task 2

Perform reverberation inversion on a number of pre-processed pings (a.k.a. reverberation time series) in order to calculate the geoacoustic properties of the trial area associated with each ping.

However, processed pings were not available for use during this contract due to reasons outside the scope of this contract. Therefore this task was not completed.



### Task 3

Using the results of the Task 2 analysis, calculate modelled transmission losses using the appropriate SWAMI modules.

Since Task 2 was not performed, Task 3 could not be done either.

### Task 4

Compare the modelled transmission losses of Task 3 to those derived from an analysis of the modelled data. In so doing, the accuracy of the inversion/transmission loss calculations may be determined.

Since Task 3 was not performed, Task 4 could not be done either.

### Task 5

Provide support in the writing of a conference presentation and scientific journal paper that will describe the reverberation inversion technique of this contract. This task is discussed in Section 3.

During the course of this contract it was hoped that processed reverberation data would become available and so allow the completion of Tasks 3, 4, and 5. However this never occurred. This allowed time for other work related to the reverberation inversion program and process to be performed. The sections that discuss these unspecified tasks and the work that was done are:

- Section 4 - A program was written to perform statistics on **BREVER** output to test the “goodness of fit” of the results.
- Section 5 - The timing of the SWAMI modules was checked to see if processing could be speeded up.
- Section 6 - Changes were made to enhance options for one of the **BREVER** input parameters.
- Section 7 - Code changes were made to SWAMI module **MONOGO** to allow eigenray model input.
- Section 8 - An initial SWAMI version of an eigenray file format was described.
- Section 9 - A more accurate way of using water depth in **BREVER** was implemented.
- Section 10 - **BREVER** results were compared to values used by SWAMI to create a “measured” data file.

Besides common English typographic conventions, the following conventions are used in this document:

- **bold text** is used for filenames (e.g. **test.pro** or **/local/files/test.pro**)
- ***bold italics text*** is used for directories (e.g. ***/usr/tmp***)
- *italics text* is used for computer names (e.g. *Grebe*)
- **Bold Arial text** is used to indicate program names (e.g. **BREVER**)
- Arial text is used to indicate function and subroutine names (e.g. PPR\_SETUP)
- *italic Arial text* is used for variable names in computer programs, the operating system, or an environment (e.g. *IDL\_PATH*)
- Courier text is used for text to be typed on the keyboard, code or text file lines, etc. (e.g. enter “idl”)

## 2. SWAMI Directional Sensor Implementation

---

Although SWAMI was originally written so as to only perform omni-directional calculations, it was given a framework that would allow the future addition of code that could perform directional calculations. This framework included descriptions of input data and parameter files that allowed the specification of directional data. In the code itself, however, the appearance of a dipole receiver was essentially ignored by not using any sort of directional weighting.

All changes needed to allow SWAMI to use directional data had to be put into the program **INTEGRATE**. To make that program process data as directional, the receiver specifications file requires that its receiver type line contain the strings “HORIZONTAL” and “DIPOLE”. As well, the line must contain instructions on the type of directional weighting to use; this must be either “CONSTANT” or “COSINE”.

A constant weighting results in a weighting factor of 1.0 to be always used, regardless of angle. This effectively treats the data as omni-directional and is what the program did before this task was performed. The new option “COSINE” results in the application of a weighting factor that is based on the cosine of the angle.

A new variable, *DWT*, was created that contained a numerical code indicating the type of dipole weighting specified in the input. The analysis routines were made to check this value and perform the required operations.

Code changes were made to the files **INTEGRATEBP.f**, **bpat\_io.f** (in its subroutines **GET\_TX\_SPECS** and **GET\_RX\_SPECS**), and **bpat\_libs.f** (the new function **DIPOLE\_WT** was written).

All code changes were made in a way that can allow other weighting schemes to be easily added, should that be desired in the future.

### 3. Conference Presentation/Scientific Paper

---

One of the tasks of the current contract was to assist the Scientific Authority in the creation of a PowerPoint presentation to be given at a Canadian Acoustical Association conference and the writing of the paper for the conference's proceedings.

The first item was the PowerPoint presentation. Information was provided to the Scientific Authority that was worked into the presentation, and editorial input was given that was used to determine the presentation's final content and appearance.

The second item was the conference paper (Theriault and Calnan [2004]). Based on specifications provided by the Scientific Authority, reverberation time series data were produced by SWAMI to be used as the "measured" data in an inversion test. The geoacoustic parameters used to produce the time series were tabulated for inclusion in the paper.

Then **BREVER** was run to obtain values for geoacoustic parameters that would create a time series whose slope produced a "best fit" to the comparison data set. Plots of the time series and their slopes were then made for the paper. Figures 1 and 3 in Section 10 are plots of the type produced for the paper.

Finally, the draft of the method section of the paper was written to describe how the program works. The Scientific Authority used this draft as the basis for the final version of that section of the paper.

## 4. Reverberation Inversion Results Statistics

---

Over the course of running test cases for the CAA paper, as described in Section 3, it was noted that results for each run were different. This was not unexpected as it is an artefact of the random manner in which ASSA obtains new test values. In fact, due to the large number of dimensions, the variability of SWAMI's sensitivity to the various input parameters, and the probable complexity of the cost function space associated with the problem, it would have been very unusual had this not happened.

Based on the fact that different results occur with each **BREVER** run an obvious question arose: when the same input values are used, how different are the results?

To solve this question, 10 **BREVER** runs were made using as the measured data the reverberation time series synthesized for the CAA paper. Then a new IDL program, **RISTATS** (reverberation inversion statistics), was written. It should be noted that **RISTATS** only produces statistics on inversion results. It does no comparisons with the geoacoustical parameter values that produced the measured data. In real world analyses this would not be possible since these values are unknown. However, Section 10 compares inversion results to values used to create a synthetic "measured" data set.

**RISTATS** must be given a file that contains a list of **BREVER** output files and the name of an output file. The program assumes that inversion runs for all the listed files used the same input data, but doesn't check for this. It does, however, check that all the listed files have the same number of radials and the same choices for the number of points/radial.

The program reads the inversion results for all parameters at all radial points on every radial in all files, and for each radial point calculates the mean and standard deviation. The output file created by **RISTATS** has three parts:

1. a listing of the files it processed,
2. the header information from the first listed file so the user can verify the inputs, and
3. the tabulated statistical results.

The tabulated results have the values for the radials' centre first, followed by points 2 to  $N$  of radial 1, points 2 to  $N$  of radial 2, and so on until all the radials have been listed. Each radial point has three lines of numbers:

1. the mean of all the values for that radial point,
2. the standard deviation of the data for that radial point in parameter units, and
3. the standard deviation of the data for that radial point as a percentage of the mean value.

The test data created for the CAA paper contained three radials with six points/radial. The **RISTATS** results for the 10 **BREVER** runs are presented in the following listing.

### Listing 1. Reverberation Inversion Statistics

Reverberation inversion statistics from files:

- 1 brever.out.01
- 2 brever.out.02
- 3 brever.out.03
- 4 brever.out.04
- 5 brever.out.05
- 6 brever.out.06
- 7 brever.out.07
- 8 brever.out.08
- 9 brever.out.09
- 10 brever.out.10

The following information is from file 1.

\*\*\*\*\*

Multiple runs for error bars

ASSA Parameters:

Initial temperature:	1.00000
Temperature scaling factor:	0.990000
Number of temp. reductions:	60
Pert/temp multiplier:	5
No. downhill simplex steps:	500
No. of averaging data sets:	100
Perturbations/temperature:	5
Perturbation value code:	1 - factor * mean of prev. 100 pert. values
Pert. value code multiplier:	3.00000
SSA convergence value:	0.01000000
Downhill simplex conv. value:	1.00000e-04

Target Parameters:

Points/radial:	fixed at 6
Density:	will vary from 1.50000 through 2.50000
Compressional sound speed:	will vary from 1700.00 through 1900.00
Compressional attenuation:	will vary from 0.150000 through 0.250000
Scattering strength:	will vary from -35.0000 through -20.0000
Depth uncertainty:	5.00000 m on interpolated depths

Radial information:

Length:	60.2000
Number of radials:	3
Bearings:	40.0000
	90.0000
	250.000

Source parameters:

Latitude: 45.0000  
Longitude: 57.5000  
Depth: 50.0000  
Heading: 90.0000  
Speed: 10.0000

Receiver Parameters:

Latitude: 45.0000  
Longitude: 57.5000  
Depth: 50.0000  
Heading: 90.0000

SWAMI program input filenames:

INTEGRATE: integ.input  
PMODES: pmodes.input  
MONOGO: monogo.input1  
monogo.input2  
monogo.input3  
CMBRAD: cmbrad.input

Measured data filename: CAA\_meas\_gv.rev  
No. of measured data values: 158

The following table(s) contain three rows of values per radial point. They are the mean values, standard deviations, and standard deviations as a %.

\*\*\*\*\*

6 points/radial  
12.0400 km between radial points

Radial	Point	Density	Compressional Sound Speed	Compressional Attenuation	Scattering Strength	Depth
	Centre	1.9709	1809.192	0.20557	-27.7781	81.99
	+/-	0.0543	7.712	0.00611	0.4309	0.56
	+/- %	2.7570	0.426	2.96992	1.5513	0.69
1	2	1.9861	1790.796	0.20249	-27.4529	78.04
	+/-	0.0409	6.919	0.00352	0.9253	0.36
	+/- %	2.0576	0.386	1.74079	3.3706	0.46
1	3	2.0140	1797.830	0.20079	-27.1740	74.67
	+/-	0.0694	9.944	0.00557	0.5386	0.33
	+/- %	3.4435	0.553	2.77209	1.9819	0.44
1	4	1.9900	1805.197	0.20017	-26.5847	72.15
	+/-	0.0683	11.068	0.00655	0.4560	0.47
	+/- %	3.4330	0.613	3.27091	1.7154	0.65
1	5	1.9937	1801.712	0.19603	-26.1479	68.05
	+/-	0.0448	10.692	0.00617	0.8563	0.60
	+/- %	2.2494	0.593	3.14550	3.2747	0.89

1	6	1.9814	1804.175	0.19730	-27.6190	62.96
	+/-	0.0618	11.655	0.00694	0.6999	0.63
	+/- %	3.1195	0.646	3.51926	2.5339	1.01
2	2	1.9903	1788.194	0.20135	-27.8592	77.57
	+/-	0.0673	15.101	0.00728	1.1204	0.77
	+/- %	3.3817	0.844	3.61588	4.0218	1.00
2	3	1.9856	1794.824	0.19903	-27.0301	67.24
	+/-	0.0670	7.003	0.00488	0.7253	0.43
	+/- %	3.3764	0.390	2.45016	2.6835	0.63
2	4	1.9917	1799.908	0.20127	-27.0558	71.17
	+/-	0.0463	15.138	0.00434	0.8769	0.58
	+/- %	2.3265	0.841	2.15710	3.2410	0.81
2	5	1.9917	1800.975	0.19742	-26.7202	75.23
	+/-	0.0705	8.104	0.00650	0.6541	0.33
	+/- %	3.5421	0.450	3.29351	2.4480	0.44
2	6	1.9779	1798.331	0.19796	-27.1997	68.06
	+/-	0.0525	10.076	0.00575	0.8904	0.51
	+/- %	2.6527	0.560	2.90617	3.2735	0.74
3	2	2.0280	1787.658	0.20370	-27.8381	90.15
	+/-	0.0560	11.596	0.00586	0.6161	0.58
	+/- %	2.7635	0.649	2.87547	2.2133	0.65
3	3	2.0082	1798.385	0.20115	-27.8291	96.01
	+/-	0.0662	12.526	0.00484	0.7254	0.73
	+/- %	3.2952	0.697	2.40477	2.6066	0.76
3	4	2.0171	1795.216	0.20085	-27.2250	85.40
	+/-	0.0561	10.850	0.00680	0.9146	0.43
	+/- %	2.7831	0.604	3.38660	3.3593	0.51
3	5	1.9902	1798.694	0.19823	-26.4633	80.21
	+/-	0.0617	9.576	0.00260	0.8253	0.55
	+/- %	3.1001	0.532	1.31289	3.1185	0.68
3	6	2.0094	1800.598	0.19806	-27.7823	73.55
	+/-	0.0272	12.149	0.00709	0.7377	0.54
	+/- %	1.3533	0.675	3.58189	2.6552	0.74

Table 1, below, presents the totals of the percentage standard deviations from the above listing when they are binned into categories of 1% each. Each data type has a total of 16 values since there were that many unique radial points.



**Table 1. Distribution of Standard Deviation Percentages**

<b>Percentage Range</b>	<b>Density</b>	<b>Compressional Sound Speed</b>	<b>Compressional Attenuation</b>	<b>Scattering Strength</b>	<b>Depth</b>
0 – 1%		16			15
>1 – 2%	1		2	3	1
>2 – 3%	7		7	6	
>3 – 4%	8		7	6	
>4 – 5%				1	

The summed results indicate that overall, results were not very widely spread, and so were quite consistent. Only one standard deviation exceeded 4%. It can also be seen that the spread of values determined for compressional sound speed and depth was the smallest.

A small spread in values could be taken to indicate that the inversion is consistently zeroing in on values that represent the “correct” values, i.e. values that lead to the best fit to the measured data. If this is correct, then it would imply that a larger spread in values might indicate that the technique is not doing a good job settling on a “correct” answer.

An alternate explanation for the amount of spread in the results is that the parameters with smaller spread have a greater influence in the SWAMI output; that the calculations are more sensitive to changes in those values. The corollary is that the equations are less sensitive to changes in the parameters with a wider spread of values.

In either case, even the largest spread of values is not particularly large. The maximum scattering strength standard deviation of 4.02% suggests that even at the worst case, **BREVER** is quite consistent in its results.

## 5. SWAMI Timing Tests

Each of the 10 runs of **BREVER** performed for the previous section required one run of the SWAMI program **INTEGRATE** and, on average, 1683 “runs” of SWAMI. (It must be remembered that a **BREVER** run can come to an end either when a maximum number of SWAMI runs has been made or a convergence factor is reached. Because of this, each **BREVER** run will probably have a different number of SWAMI runs.) For **BREVER**’s purpose, each Section 4 SWAMI run consists of one run of **Pmodes** and **CMBRAD** plus 3 runs of **MONOGO**. The difference with **MONOGO** is that it must be run once for each radial, and the test data have three radials. The input data also consisted of 6 points/radial, and since the central point was a common one, there were 16 unique radial points.

The number of calculations required in an ASSA analysis is a function of the number of unique radial points times the number of parameters being solved for, a product that is referred to as the number of dimensions. In ASSA the number of required calculations rises at a much faster rate than the number of dimensions. In general it would be quite easy for an analysis to require more than three radials, each with many more than six points/radial.

Accordingly a number of **BREVER** runs were made using a varying number of points/radial and the amount of time each program took to run was noted. For this test each case only had one radial. The results are displayed in Table 2.

Table 2. SWAMI Timing Runs

Program	6 points/radial	20 points/radial	81 points/radial
<b>INTEGRATE</b>	6 s	6 s	5 s
<b>Pmodes</b>	< 0.5 s	1 s	3 s
<b>MONOGO</b>	13 s	10 s	17 s
<b>CMBRAD</b>	< 0.5 s	< 0.5 s	< 0.5 s

**INTEGRATE** is only run once per **BREVER** run and seems to be insensitive to the number of radial points, so its timing was not a concern.

**Pmodes** timing is apparently related to the number of radial points, but is not the major timing bottleneck.

**CMBRAD** takes about the same amount of time regardless of conditions and so is also ignored.

**MONOGO** is the program that takes longest to run, although the number of points/radial doesn’t seem to be an important factor. However it must be remembered that there was only one radial in the test data, and the program is run once for each

radial. Accordingly it was decided to examine **MONOGO** in order to see if there was any way to speed up the processing.

As it turns out, there were no obvious significant inefficiencies in the code. A few small code changes were made that tightened it up somewhat and reduced the processing steps, but their effect on timing changes is miniscule. This is mainly due to the program's efficiency, but may also be in part due to the maturity of the FORTRAN compiler used to produce the program's executable. A properly written compiler can overcome a plethora of programming inefficiencies by optimizing the code during compilation.

However, the fact that **MONOGO** is the main timing bottleneck in **BREVER's** processing should be remembered. Then, any time that **MONOGO's** source code is changed for any reason, programmers should do their utmost to make the new code as efficient as possible.

## 6. Changes to BREVER Input

---

Calnan [2004] contains, among other things, instructions on how to run **BREVER** and a description of the input files needed by that program. The initial file used by that program is referred to in that report as the “**BREVER** primary input file”, and it is described in Section 3.1 and its subsections.

In the course of performing the work for the current project two changes were made to the format of the **BREVER** primary input file. This section describes these changes, which were made to data line 6, which instructs **BREVER** on how many points/radial to solve for, and 20, which gives the name of the reverberation time series data file being used as a basis for comparison. This comparison file is usually referred to as the “measured” data file, although it may very well have been synthesized by a model. This was the case for the test data described in Sections 3, 4, and 10 of this report.

Except for the data on these two lines, everything else is unchanged and the earlier report can be used for the creation of the file and for instructions on how to run **BREVER**.

### 6.1 Data Line 6: Points per Radial

One option **BREVER** uses in its search for the best-fit geoacoustical parameters is the number of points on the radials. This information occurs on data line six of the **BREVER** primary input file, as described in Section 3.1.1 of Calnan [2004].

This information consisted of two integers, described in that report in this way:

*This line indicates the minimum and maximum number of points/radial to use in the testing. The program steps from the minimum to the maximum number in steps of 1, and performs a full analysis for each step.*

*Rules on the minimum/maximum limits are:*

- *the minimum must be 1 or greater*
- *the maximum must be at least the minimum*

Upon further reflection, it was realized that users might not want to be restricted in this manner. Therefore the manner in which **BREVER** processes the contents of that data line was changed to that of Suggestion 2 in Section 6 of the earlier **BREVER** report. The new scheme allows users to specify particular numbers of points/radial to use, ranges incremented by a defined amount, and even exclusions within ranges. Among other choices, this allows users to perform several analyses with the same number of points/radial, the results of which could be used to determine the variation in the resulting answers, as is described in Section 4. The following table lists the types of entries that are possible under the new scheme.

**Table 3. Points/Radial Options**

<b>Data Line 6 Contents</b>	<b>Program Action</b>
25	solves for 25 points/radial (PPR)
2 12 5 12	solves for 2, 12, 5, and 12 PPR
2 :5 14 : 12	solves for 2, 3, 4, 5, 14, 13, and 12 PPR
2 to 24 by 5	solves for 2, 7, 12, 17, and 22 PPR
2:100 x 12 x21:29	solves for all PPR values from 2 to 100 except for 12 and 21 through 29
2:10 8 12 to 25 by 4 88 x 5	solves for 2 through 10 except for 5, 8 a second time, 12, 16, 20, 24, and 88 PPR

The rules that **BREVER** applies to the data line six input are:

- 2 is the smallest points/radial value allowed.
- Points/radial values are solved for in the order they are entered
- A specific points/radial number may be specified any number of times.
- The list of points/radial numbers is built up from left to right, so an excluded value might be added again later.

## 6.2 Data Line 20: Measured Data File

Data line 20 of the **BREVER** primary input file, as described in Section 3.1.1 of Calnan [2004], contains the name of a file containing a reverberation time series. **BREVER** produces values for geoacoustical parameters that result in a reverberation time series with the closest possible slope match to the data in this file.

The original intent was that this file would always be a DRDC .DAT or .DAT32 format file, and **BREVER** was written to only read that type of file. However, in the course of the current project it was realized that comparison data might be presented in other formats. In fact the data file for all tests run in this case was a SWAMI-produced file.

Two programming options were available to allow for different input file formats:

- change the code every time a new format file is to be used, or
- allow for expansion and add to the list of permissible formats.

The latter option was chosen, but this required that **BREVER** be told what the input file's format is. This was done by adding a second parameter to data line 20.

Originally the line only contained the name of the input file, but now it must contain two items: the format of the file and the file's name. So far the program can only

accept either .DAT, .DAT32, or SWAMI format files. The file's format is indicated by using the flag ".DAT" for a .DAT or .DAT32 file or "SWAMI" for a SWAMI format file.

Examples of this are the lines:

" .DAT     jun08.dat"   -   which tells the program that the file **jun08.dat** is in either .DAT or .DAT32 format; the program is able to determine which format the file is in

"SWAMI     jul17.dat"   -   which tells the program that the file **jul17.dat** was created by SWAMI or is in the format of a SWAMI created file

As other formats are required new format flags may be devised for them and the appropriate **BREVER** routines may be expanded. READ\_BREVER\_IN is the subroutine that reads the **BREVER** primary input file (or most of it) and READ\_MEAS\_DATA is the subroutine that reads in the measured data file. Both routines are called from the main program.

## 7. Eigenray Input for MONOGO

---

### 7.1 Introduction

The SWAMI component **PMODES** produces data files with information needed by **MONOGO** to produce reverberation time series. **PMODES** must be run once for every new set of test geoacoustical parameter values. As well, since the program is range-independent it must be run for each range on each radial. In other words, if there are 12 points/radial, it must be run 12 times for the first radial and 11 times for each of the other radials. (The centre point is common to all radials and so only needs to be processed once.)

The Oceans Acoustics Library web site freely distributes the acoustic prediction model **Bellhop**. This program uses range dependant ray theory calculations to produce eigenray data that include the various parameters required by **MONOGO**, albeit in a somewhat different format than does **PMODES**.

Since there are cases where **Bellhop** output is more suitable than **PMODES** output, it was decided that SWAMI should be expanded to include the option of using a version of **Bellhop**. This would allow SWAMI users to choose between **PMODES** and **Bellhop** as required for a particular problem. As a consequence of this expansion, it would then be useful to modify **BREVER** so that it could use either **Bellhop** or **PMODES** as part of its reverberation inversion analysis.

Since **Bellhop** has its own procedures for being used, none of which require input files from prior routines, only **Bellhop** output has to be dealt with. In the course of running SWAMI in its current form, the output from **PMODES** is processed by **MONOGO**. Since **Bellhop** will be replacing **PMODES**, this means that **MONOGO** must be expanded to handle **Bellhop** output files.

This presents two problems:

1. **MONOGO** must be told that the input file is a **Bellhop** eigenray file.
2. **MONOGO** must then read in the data and use it appropriately.

There is the further constraint that no changes must be allowed to interfere with the way in which **MONOGO** currently works.

### 7.2 MONOGO Input

The first problem was dealt with by creating the “global” COMMON area variable **TLMODEL** (transmission loss model), which is set to 1 when **PMODES** input will be used and 2 when **Bellhop** input will be used. Actually the value 2 will be used whenever eigenray input data are used; for now the only source for this is **Bellhop**.

One of the input files used by **MONOGO** is an environment description file, known as a “.des” file. If a user wishes to use **Bellhop** eigenray files as input to **MONOGO** then a change must be made to the .des file. There is a line in that file that contains the text strings “RADIAL” and “INFORMATION”; this line must be changed so that it also contains the string “EIGENRAY”. (All strings may be entered in any mixture of upper and lower case characters since the strings are completely converted to upper case before being parsed.) If the string “EIGENRAY” is omitted then **MONOGO** will set *TLMODEL* to 1 and its processing will proceed as it did prior to the eigenray code changes. The appearance of the string “EIGENRAY” will result in *TLMODEL* being set to 2. Whenever **MONOGO** has to choose between **PMODES** and **Bellhop** related operations it checks the value of *TLMODEL*.

To use eigenray input for **MONOGO** results in the following constraints on the contents of the .des file:

1. The “GRADIENT =” line must contain the name of a bathymetry profile file. The file must have the same format as for **PMODES** input, its first range must be zero, and the last range can not be less than the greatest distance range in the eigenray file. **MONOGO** will check for a filename and later verify that the distance the ranges in the file are valid. If any errors are found they will be reported and **MONOGO** will stop with an error condition.
2. The “RADIAL INFORMATION” line must contain the word “EIGENRAY”, thus making the line “RADIAL INFORMATION EIGENRAY”.
3. The line immediately following the “RADIAL INFORMATION EIGENRAY” line must contain the name of a **PMODES**-format .env file. The file’s sound speed profile will be read and used to determine sound speeds for the depths of the eigenray file. This means that the depths must increase, the first depth can not be greater than the eigenray file’s minimum depth, and the last profile depth can not be less than the eigenray file’s maximum depth.
4. Only one eigenray file may be named after the “RADIAL INFORMATION EIGENRAY” line, and that file must contain data for all the distances for which calculations are required.

## 7.3 MONOGO Changes

After reading the .des file, setting *TLMODEL* appropriately, and verifying the .des file contents, **MONOGO** branches its processing depending on the value of *TLMODEL*.

If *TLMODEL* = 1 then **MONOGO** calls subroutines that read the **PMODES** output files and, if necessary, zero-fill some arrays. The *TLMODEL* = 2 processing analogue is to call the new subroutine **EIGEN\_READ**, which reads in the eigenray file. **EIGEN\_READ** is already operational, has been tested and put into **swami\_io.f**, and will be called from **MONOGO** if the .des file indicates eigenray input.



Later, *TLMODEL* = 1 causes the subroutine *CMP\_BPATS* to be called. If a beam pattern data file is available this routine reads that file's contents and calculates the beam pattern data for later use. If *TLMODEL* = 2 **MONOGO** calls the new subroutine *READ\_ER\_BPAT*. That subroutine is a copy of *CMP\_BPATS* that only reads the beam pattern data files. The calculations aren't performed immediately since eigenray data require different calculations than do normal mode data. The new subroutine *READ\_ER\_BPAT* has been put into **swami\_io.f** and will be called from **MONOGO** if the **.des** file indicates eigenray input. However it hasn't been tested yet due to a lack of appropriate data files.

Finally, **MONOGO** calls *MONOSTATIC\_RD* for both input data types. That results in the calculation and production of the reverberation time series output file.

*MONOSTATIC\_RD* was edited so that one of two processing paths is taken depending on *TLMODEL*'s value. A value of 1 results in its original processing being performed, although a large chunk of code was moved into the new subroutine *PC\_NORMAL* (pressure calculation for **normal** mode data).

If *TLMODEL* = 2 the new subroutine *PC\_EIGEN* (pressure calculation for **eigenray** data) is called. That subroutine performs the required calculations and returns the reverberation data to the calling routine. It also calls two routines during its operation, a new one and an existing one.

The new routine that *PC\_EIGEN* calls is *CALC\_ER\_BPAT* (calculate **eigenray BPAT**, where *BPAT* is an array that holds beam pattern results). This subroutine is called for each eigenray range to calculate the values of the beam pattern component of the output reverberation data. It is a variation on part of the existing **swami\_io.f** subroutine *CMP\_BPATS* that was modified to use eigenray data.

Once *PC\_NORMAL* or *PC\_EIGEN* returns to *MONOSTATIC\_RD*, that routine prints out the reverberation time series. Following that it returns to the main program **MONOGO**, which exits.

## 7.4 MONOGO Expansion Status

The full eigenray expansion of **MONOGO** is completed, as near as can be determined. However without suitable input data files the program could not be tested and debugged. As well, in setting up SWAMI to use **Bellhop** it is quite possible that further changes to this routine may be required.

The use of eigenrays in **MONOGO** required the writing of four new subroutines. Two of them, *EIGEN\_READ* and *READ\_ER\_BPAT*, are called from **MONOGO** directly and deal with reading input, and so were immediately put into **swami\_io.f**.

A third subroutine, *PC\_EIGEN*, was put into **ogomonRD.f**.

The last new subroutine is `CALC_ER_BPAT`, which was added to `swami_cmp.f`.

The only eigenray related test performed on **MONOGO** was to ensure that the addition of eigenray code did not affect the processing when non-eigenray environments were used. The program passed this test.

## 7.5 Bellhop Modification

**Bellhop** may require some modifications as well. At the very least its output file format will have to be changed to match the eigenray file format that **MONOGO** will require. However, it may happen that both **Bellhop** and **MONOGO** will be changed further to accommodate a new, and different, agreed-upon format.

In a similar vein, no standard has yet been settled upon for the input environment data file that **Bellhop** needs. This will also have to be coordinated with **MONOGO** (and possibly **PMODES**), depending on how the **Bellhop**-enabled version of SWAMI develops.

## 7.6 BREVER Eigenray Expansion

**BREVER** will have to be modified as well. At the very least the program's input file will have to be changed so that it runs **Bellhop** instead of **PMODES** and creates `.des` files that tell **MONOGO** to expect eigenray data instead of **PMODES** output files. It is likely that as the **Bellhop** SWAMI is made to work other **BREVER** changes will become apparent.

## 8. SWAMI Eigenray File Format

---

Page 3-4 of Weinberg [1985] describes the format of the Naval Underwater Systems Center's Generic Sonar Model (GSM) eigenray file, which contains eigenrays indexed by range and frequency.

The model **Bellhop** is able to produce eigenray data indexed by range, frequency, and depth. It would be useful to define a binary file format similar to that of GSM's eigenray file in which to store **Bellhop**'s eigenrays for use in SWAMI, and by extension **BREVER**. In fact a successful file format could store range/frequency/depth indexed eigenrays ("RFDEIGs") regardless of their source. Once a suitable format is decided upon, **Bellhop** may be edited so as to produce files in that format.

One eigenray file format option was to use GSM's. However that format does not allow the environment to change with depth, unlike **Bellhop**. To simplify the production of **Bellhop** output and reduce file sizes (binary vs. ASCII), an attempt was made to see if **Bellhop** output could be shoehorned into GSM's eigenray file format.

The result: almost. Since GSM's eigenrays are range and frequency indexed, the possibility of replacing frequency data with depth data (minimum, maximum, and step size) was considered. However it was decided that this scheme was unsatisfactory as it resulted in the loss of the frequency data, thus making the file unsuitable for models such as **WATTCH**.

However, an examination of the GSM eigenray file header revealed some unused bytes that could be appropriated for the depth data. Unfortunately no low-hazard way could be found to store the depth indexing in the space allocated for each eigenray's data. Reluctantly it was decided to change the format, only "breaking" it slightly. The changes involved making use of the unused header bytes without changing its size, and adding one new parameter to each eigenray's data.

The latter change would definitely cause breakage if any programs used to read GSM output were used on one of the new files. But, by specifying the file's type in its first six bytes with an identifier unknown to GSM, and with the assumption that all programs that read GSM output first verify the files' types by checking this identifier against valid identifiers, it was felt that the danger was minimized.

Accordingly, the following proposed RFDEIG file format was devised, based on the GSM eigenray format. By keeping it as close as possible to the GSM format it was hoped that any routines that currently read GSM eigenray data files would only require minimal changes in order to read the new format.

This proposed format is still tentative, however. As the **Bellhop** SWAMI model is developed it may happen that further changes to this format may be required.

The format is presented in the next two tables. The first, Table 4, describes the header of the new format, which consists of 76 bytes of data, the same as the GSM eigenray file header.

**Table 4. Proposed Bellhop Eigenray File Header**

Bytes	FORTTRAN Data Type	Contents	
1-6	CHARACTER*6	“FRDEIG”	indicates frequency/range/depth indexed eigenrays
7-10	REAL*4	<i>RNGMIN</i>	range minimum (km)
11-14	REAL*4	<i>RNGMAX</i>	range maximum (km)
15-18	REAL*4	<i>RNGDEL</i>	range increment (km)
19-22	REAL*4	<i>FRQMIN</i>	frequency minimum (Hz)
23-26	REAL*4	<i>FRQMAX</i>	frequency maximum (Hz)
27-30	REAL*4	<i>FRQDEL</i>	frequency increment (Hz)
31-34	REAL*4	<i>FRQGAM</i>	frequency factor
35-38	REAL*4	<i>SRCDPT</i>	source depth (km)
39-42	REAL*4	<i>TRGDPT</i>	target depth (km)
43-46	REAL*4	<i>BTMDPT</i>	maximum bottom depth (km)
47-50	REAL*4	<i>DEPMIN</i>	depth minimum (km)
51-54	REAL*4	<i>DEPMAX</i>	depth maximum (km)
55-58	REAL*4	<i>DEPDEL</i>	depth increment (km)
59-64	CHARACTER*6		not used
65-70	CHARACTER*6	<i>SORT</i>	sorting order used to write the file (“RN”, “FR”, “DE” indicate, respectively, range, frequency, depth): “FRRNDE” – frequency, range, and depth; “DERNFR” – depth, range, and frequency; etc.
71-76	CHARACTER*6	<i>EIGMDL</i>	eigenray model (“BELHOP” for <b>Bellhop</b> data)

The rest of the records in the file all contain 128 eigenrays worth of data. Each eigenray is described by 10 words. The following table describes one eigenray’s worth of data.

**Table 5. Proposed Bellhop Eigenray File Data Layout**

Word	FORTTRAN Data Type	Contents	
1	INTEGER*4	<i>IDEP</i>	depth index; <i>IDEP</i> < 1 indicates end of the file's data
2	INTEGER*4	<i>IRNG</i>	range index
3	INTEGER*4	<i>IFRQ</i>	<i>IFRQ</i>   = frequency index; if <i>IFRQ</i> < 0 semi-coherent addition is being used
4	INTEGER*4	<i>NSRF</i>	<i>NSRF</i>   = number of upper reversals; if <i>NSRF</i> > 0 → surface intersection if <i>NSRF</i> < 0 → upper vertex
5	INTEGER*4	<i>NBTM</i>	<i>NBTM</i>   = number of lower reversals; if <i>NBTM</i> > 0 → bottom intersection if <i>NBTM</i> < 0 → lower vertex
6	REAL*4	<i>SRCANG</i>	source angle (rad)
7	REAL*4	<i>TRGANG</i>	target angle (rad)
8	REAL*4	<i>TIMEIG</i>	travel time (s)
9	REAL*4	<i>AMPEIG</i>	relative pressure amplitude referred to the range
10	REAL*4	<i>PHSEIG</i>	pressure phase (rad)

The differences between the proposed format and that of GSM eigenray files are:

- header bytes 47-58 are used,
- header bytes 65-70 have different sorting strings, and
- the first word on each eigenray's data record, *IDEP*, is new.

## 9. BREVER Water Depths

---

Among the geoacoustic parameters **BREVER** can solve for are water depths at the radial points. To perform this task **BREVER** reads in the bathymetry profile depths and uses these values as initial estimates. While performing an inversion **BREVER** randomly changes the water depths at the radial points within a user-supplied range that brackets the input profile depths. These new test values are written into the **PMODES** input file, which uses them to produce its output.

**MONOGO** reads **PMODES** output and uses the data in the file to produce the reverberation time series. However **MONOGO** also requires bottom gradients in its calculations. As originally written, **BREVER's** instructions to **MONOGO** caused that program to read the original bathymetry profiles and calculate gradients from these depths. This, upon reflection, can be seen to be incorrect since the depth data used to calculate the **PMODES** output is not the same as the depth data used to calculate gradients.

The correct technique would be to have **MONOGO** use the same depth data as were used by **PMODES**. Fortunately these data are available since **PMODES** puts the depths it used in its output files. Accordingly, **BREVER** was modified to tell **MONOGO**, via the **.des** files, to use the **PMODES** output file depths instead of the original bathymetry profile depths.

It is expected that this change will help improve the results of the reverberation inversion.

## 10. BREVER Test Results

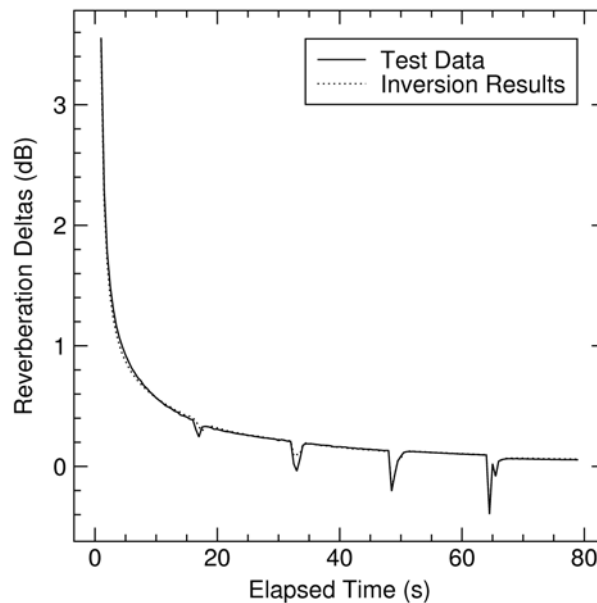
---

After the water depth related correction of Section 9 was made to **BREVER**, an inversion run was made using the reverberation time series created for the CAA paper, mentioned in Section 3. The reason for doing this was to compare the resulting geoaoustical parameters with those used to create the “measured” reverberation time series data file.

It must be remembered that **BREVER’s** criterion for fitting reverberation time series data is not to match the time series themselves, but to try to get the best fit for the slopes of the curves. Since the measured data and the output time series start at the same time and have the same sized time step, slope-equivalents may be produced by subtracting each reverberation value from the preceding value in the time series. The resulting slopes will match up as best as the program can determine given its input constraints, but these best fits will result in actual reverberation values that are roughly parallel. One reason for choosing this method is that it eliminates knowing the exact gains involved in recording the measured data.

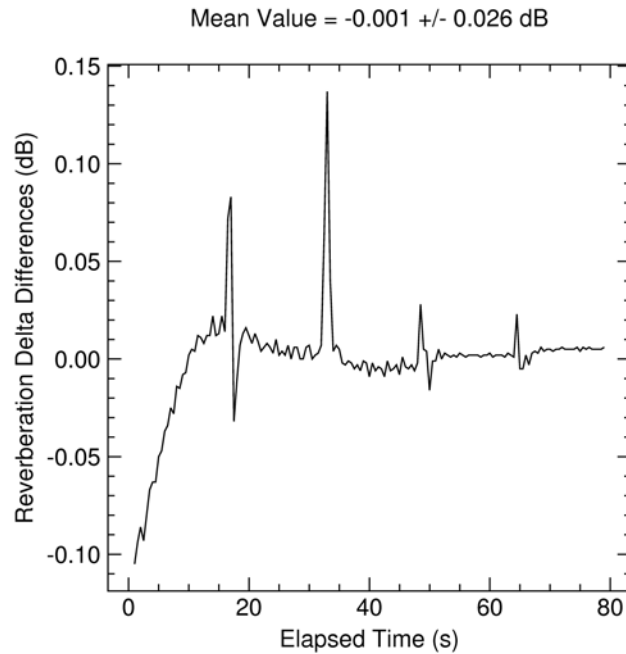
The option of making a number of runs and averaging the results was considered, but dismissed, as it was desired to see how a single inversion run would fare.

Figure 1 is a plot of the “slope”, referred to here as “Reverberation Deltas”, calculated from the “measured” and inversion-produced reverberation time series.



**Figure 1. Reverberation Delta Time Series**

It can be seen that the two curves are very close together, indicating a good fit of the results. The following diagram, Figure 2, quantizes these differences by plotting the actual differences between the measured and model values at the same times.

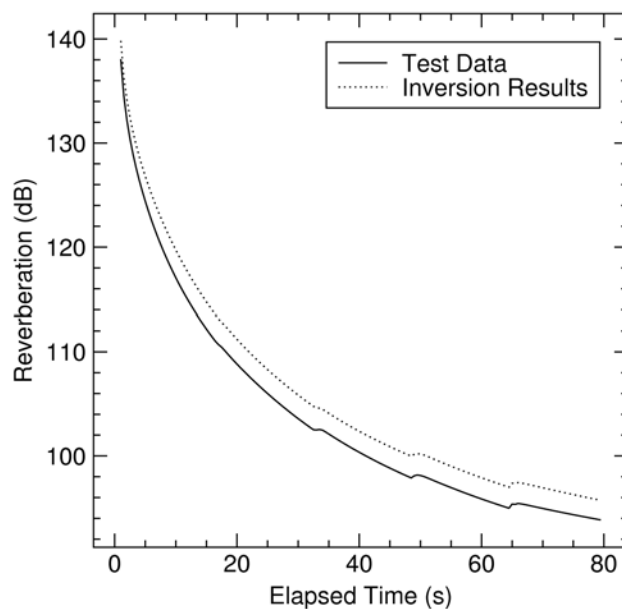


**Figure 2. Reverberation Delta Differences: Results minus Measured**

This diagram shows that the differences between the two “slopes” are quite small, with the largest differences occurring at the start of the time series and at the locations of the intermediate radial points. This will be mentioned following the discussion of Figure 4.

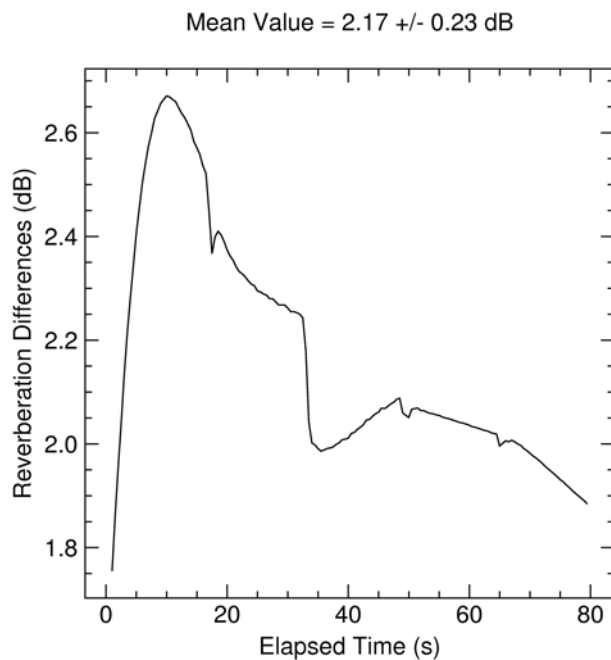
Figure 3 presents the measured and **BREVER** best fit reverberation time series. It clearly shows the tendency of **BREVER** to produce geoacoustical parameter values that result in a reverberation time series that is offset from the measured data by a fairly constant amount, as is described above.





**Figure 3. Reverberation Time Series**

The next diagram, Figure 4, is an analogue of Figure 2 in that it presents a time series of the differences between the two curves at each time step.



**Figure 4. Reverberation Differences: Results minus Measured**

The differences between the two curves average around 2% of the reverberation levels, and the variation is about one-tenth of that. This indicates that the two curves are fairly parallel, something referred to in the second paragraph of this section.

Due to the way the overall SWAMI environment was set up, a new **PMODES** environment file is used about every 16 seconds in the time series. **MONOGO** appears to have a problem with changes in the environment files, as can be seen in the “bumps” in the four figures at multiples of 16 seconds. This is addressed in Section 12 as Suggestion 2.

Table 6, below, presents geoacoustical information for each radial point. There are three values for each point, and they present, from top to bottom, the value used to create the “measured” data, the value that **BREVER** solved for, and the absolute value of the percentage error of the **BREVER** result. The last line in the table, labelled “Overall Mean”, presents the average percentage error for each parameter.

**Table 6. BREVER Results v. Original Data**

Radial	Point	Density	Compressional Sound Speed	Compressional Attenuation	Scattering Strength	Depth
Centre		2.0700	1782.000	0.21800	-29.3000	83.00
		2.0257	1807.083	0.19743	-27.9879	82.71
		2.14%	1.41%	9.44%	4.48%	0.35%
1	2	2.0100	1786.000	0.21200	-28.7000	78.00
		1.8769	1795.511	0.20892	-29.2357	78.37
		6.62%	0.53%	1.45%	1.87%	0.47%
1	3	1.9400	1792.000	0.20700	-27.6000	75.00
		1.9857	1812.739	0.20487	-27.8941	74.91
		2.36%	1.16%	1.03%	1.07%	0.12%
1	4	1.8600	1799.000	0.20300	-26.8000	72.00
		1.9935	1784.367	0.19692	-26.4283	71.80
		7.18%	0.81%	3.00%	1.39%	0.28%
1	5	1.7800	1810.000	0.19800	-26.2000	68.00
		2.0225	1795.099	0.19817	-24.9717	67.99
		13.62%	0.82%	0.09%	4.69%	0.01%
1	6	1.7300	1818.000	0.19300	-25.3000	63.00
		1.9713	1799.457	0.18971	-27.2778	62.78
		13.95%	1.02%	1.70%	7.82%	0.35%
2	2	2.0500	1788.000	0.21600	-29.3000	78.00
		2.0647	1789.612	0.19723	-27.6335	78.51
		0.72%	0.09%	8.69%	5.69%	0.65%
2	3	1.9900	1794.000	0.21400	-28.9000	67.00
		2.0136	1785.438	0.20456	-27.0810	67.52
		1.19%	0.48%	4.41%	6.29%	0.78%

Radial	Point	Density	Compressional Sound Speed	Compressional Attenuation	Scattering Strength	Depth
2	4	1.9500	1801.000	0.21300	-28.2000	71.00
		1.9736	1802.914	0.20338	-26.4167	70.96
		1.21%	0.11%	4.52%	6.32%	0.06%
2	5	1.9100	1807.000	0.21200	-27.4000	75.00
		1.9527	1791.740	0.20357	-26.1909	74.88
		2.24%	0.84%	3.98%	4.41%	0.16%
2	6	1.8500	1812.000	0.21100	-26.6000	68.00
		2.0666	1797.385	0.19700	-27.9207	68.61
		11.71%	0.81%	6.64%	4.97%	0.90%
3	2	2.1300	1776.000	0.22100	-29.3000	90.00
		2.1250	1786.866	0.21378	-27.2340	89.40
		0.23%	0.61%	3.27%	7.05%	0.67%
3	3	2.1800	1771.000	0.22200	-29.0000	96.00
		2.0218	1802.170	0.19869	-27.7715	96.67
		7.26%	1.76%	10.50%	4.24%	0.70%
3	4	2.2200	1765.000	0.22500	-28.4000	85.00
		2.0006	1806.902	0.20240	-27.5534	85.26
		9.88%	2.37%	10.04%	2.98%	0.31%
3	5	2.2500	1758.000	0.22700	-27.6000	80.00
		1.9515	1813.314	0.19675	-27.1538	79.95
		13.27%	3.15%	13.33%	1.62%	0.06%
3	6	2.2800	1753.000	0.22900	-26.9000	74.00
		2.0348	1813.795	0.20482	-28.2265	74.25
		10.75%	3.47%	10.56%	4.93%	0.34%
Overall Mean		6.52%	1.21%	5.79%	4.36%	0.39%

It can easily be seen that the smallest mean absolute percentage errors occurred in determining the depth and compressional sound speed. Interestingly enough, these are the two parameters that had the minimum spread of values in the multiple run test, as seen in Table 1 in Section 4.

In the current test, where the **BREVER** was using SWAMI to match the slope of a curve that was created by SWAMI, it's possible that if **BREVER** had been written to try and match up the reverberation time series directly, the curves may have had less than an average separation of 2.17%. And in that case, it's also possible that the resulting parameters might have been even closer that is displayed in the above table. However, this idea wasn't tested since the program does not use a comparison between time series as its best fit criterion.

## 11. File Locations

---

All the work done for this project was performed on *Grebe*, and so all the code and files produced for or used in this project are on that computer.

- the programs that comprise **BREVER** are located in */home/calnan/projects/RevInv/code*
- the SWAMI code is located in */home/calnan/projects/RevInv/dmos*
- the SWAMI program executables are located in */home/calnan/projects/RevInv/dmos/bin*
- the code for the updated eigenray version of **MONOGO** is not yet integrated into the */bin* version of **MONOGO**, but are located in */home/calnan/projects/RevInv/dmos/monogo*
- **SAPLOT** is located in */home/calnan/projects/idllib/SAPLOT*
- the material produced for the conference and CAA paper and the reverberation results statistics are located in */home/calnan/projects/RevInv/caa-run* and its subdirectories */fake\_data* (the material used to create the “measured” data) and */for\_Jim* (material prepared for the Scientific Authority to use in the paper)
- the comparison between the data used to create the CAA paper’s “measured” data and **BREVER** results, as shown in Section 10, was done in */home/calnan/projects/RevInv/caa-run/breвер\_test*

As well, directory */home/calnan/projects/HPA/code* has two IDL programs that make it simple to examine a measured data file in .DAT or .DAT32 format:

- **READ\_HDR** (main file *read\_hdr.pro*) reads the file header and writes it to the screen. To save this data in a file, a user can either start IDL and redirect its output to a file, or cut and paste the text written to the screen.
- **VIEW\_DAT** (main file *view\_dat.pro*) produces screen, and optionally PostScript file, plots of user selected portions of a .DAT or .DAT32 file.

It may be noted that some IDL files with the same name exist in more than one directory. This is particularly true of directories */home/calnan/projects/RevInv/code* and */home/calnan/projects/HPA/code*. A user must not assume that the files are identical. The HPA code was written first and then adopted for use with **BREVER**. Some of the programs have had their capabilities enhanced and so can not be blithely exchanged back and forth.

## 12. Suggestions for Further Work

---

This section has some suggestions for further work that may be performed relating to the current contract. The earlier report on **BREVER** contained five suggestions in Section 6, one of which was implemented during the course of this project, as described in Section 6.1. Two of the others (allowing the fixing of specific parameters and allowing multiple fixed values) are probably unworkable due to the possibility that the number of points/radial can vary. However the other two suggestions are still valid and are repeated here as Suggestions 1 and 2. The other suggestions in this section arise from work on the current contract.

### Suggestion 1: Expand **READ\_PMODES\_IN**

The function **READ\_PMODES\_IN** can't handle the input **PMODES** options "T" and "O". Currently if either of these options is present the function reports the fact and exits. It would not be a major task to modify the function to handle the options properly.

### Suggestion 2: **MONOGO** modification

**MONOGO** currently operates by reading a **PMODES**-created environment description file and using it until a new one is presented to it. This can result in discontinuities in the results if consecutive environments have different parameters, something noticeable in Figures 1 and 3. **MONOGO** either has a bug that prevents a smooth transition between environments or lacks the coding to make the transition. In either case the program could be examined in order to produce a smoother transition between adjacent areas.

### Suggestion 3: Perform Reverberation Inversion

Ping data were not processed into a format that allowed them to be inverted. This resulted in the contract Tasks 2, 3, and 4 not being performed, as is discussed in Section 1. When the data are eventually prepared as required by **BREVER**, these analyses may be performed.

### Suggestion 4: Finish **SWAMI Bellhop** implementation

As is described in Section 7, this project permitted the start of the work required to allow **SWAMI** to use **Bellhop** as a replacement for **PMODES** as the program that produces the required environment. This work could be completed.

### **Suggestion 5: Add Bellhop-SWAMI Capabilities to BREVER**

Once **Bellhop** has been added to SWAMI, **BREVER** could be expanded to use these added abilities. It is not likely that the work involved in this task would be particularly difficult. This is due to the original layout of **BREVER**, which was designed to allow the expansion or swapping of processes. As far as users are concerned, the main difference would be a slightly modified **BREVER** primary input file format. This might be as minimal as an extra (or modified) line that tells the program which of **PMODES** or **Bellhop** to use. However, it is possible that using **Bellhop** might require more information from the user than is required by **PMODES**; this is something that an examination of **Bellhop** would disclose.

### **Suggestion 6: Update SWAMI Documentation**

The main source of information on SWAMI is an HTML document that was written several years ago. Since that time programs that SWAMI includes have been replaced (e.g. **OGOPOGO** has been replaced by **MONOGO**), file formats have changed, and so on. It would be useful to update this document to have it reflect the current state of the model. As well, once **Bellhop** has been successfully worked into SWAMI, information on that program should also be included in the SWAMI document.

## Bibliography

---

- Calnan, C. (2004). *Reverberation Inversion Using SWAMI* (DRDC Atlantic CR 2004-113, December 2004).
- Theriault, J.A., and Calnan, C. (2004) SWAMI and ASSA for Geoacoustic Inversion, Proc. 2004 Canadian Acoustical Association Symposium, Canadian Acoustics, October 2004.
- Weinberg, H. (1985) *Generic Sonar Model* (NUSC Technical Document 5971D, 6 June 1985)

## Initialisms and Acronyms

---

ASCII	American Standard Code for Information Interchange
ASSA	Adaptive Simulated Simplex Annealing
DASM	Directional Acoustic Sensor Module
DRDC	Defence Research and Development Canada
GSM	Generic Sonar Model
HPA	Horizontal Projector Array
SWAMI	Shallow Water Active-sonar Modelling Initiative
TIAPS	Towed Integrated Active-Passive Sonar



## Distribution List

---

### Internal Distribution

2	DRDC Atlantic LIBRARY FILE COPIES
4	DRDC Atlantic LIBRARY (SPARES)
3	J. Theriault
1	S. Pecknold
1	M. Boutin
1	D. Ellis
1	P. Hines
1	M. LeFrancois
1	B. Roger

### External Distribution

1	AUTHOR
1	LCdr W. Renauld, SSO METOC, MARLANT CFB Halifax
1	D. McGaughey, Dept Electrical and Computer Engineering Royal Military College of Canada Box 17000, Station Forces Kingston, Ontario, K7K 7B4
1	R. Marsden, Dept Electrical and Computer Engineering Royal Military College of Canada Box 17000, Station Forces Kingston, Ontario, K7K 7B4
1	M. Prior, NATO Undersea Research Center
1	S. Taylor Defence Science and Technology Organization
1	C. Burt Defence Science and Technology Laboratory
1	NDHQ/ CRAD/ DRDKIM 3

**Total 23 copies**

DOCUMENT CONTROL DATA		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)		
1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)  <b>Xwave</b> <b>36 Solutions Drive, Halifax, NS B3S 1N2</b>		2. SECURITY CLASSIFICATION <input checked="" type="checkbox"/> (overall security classification of the document including special warning terms if applicable).  <b>UNCLASSIFIED</b>
3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title). <b>TIAPS "Through the Sensor Probing" Technique</b>		
4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)  <b>C. Calnan</b>		
5. DATE OF PUBLICATION (month and year of publication of document)  <b>March 2005</b>	6a. NO. OF PAGES (total containing information Include Annexes, Appendices, etc). <b>46 (approx.)</b>	6b. NO. OF REFS (total cited in document)  <b>3</b>
7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered).  <b>CONTRACT REPORT</b>		
8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include address). <b>Defence Research &amp; Development Canada – Atlantic</b> <b>PO Box 1012</b> <b>Dartmouth, NS, Canada B2Y 3Z7</b>		
9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant).  <b>11cm</b>	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written).  <b>W7707-04-2580</b>	
10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor.)  <b>DRDC Atlantic CR 2005-033</b>	
11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification) ( <input checked="" type="checkbox"/> ) Unlimited distribution (    ) Defence departments and defence contractors; further distribution only as approved (    ) Defence departments and Canadian defence contractors; further distribution only as approved (    ) Government departments and agencies; further distribution only as approved (    ) Defence departments; further distribution only as approved (    ) Other (please specify):		
12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected).		

13. **ABSTRACT** (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

An earlier contract (Calnan [2004]) resulted in the creation of BREVER, a program able to perform reverberation inversion on processed ping data from TIAPS sea trials. The inversion results, which are the geoacoustical properties of the pings' environments, could be used to calculate transmission losses in these environments.

This contract was let to perform inversions on a number of pings, calculate transmission losses, and compare the results to those obtained from other means. This contract was also intended to permit enhancement of the reverberation program and assist the Scientific Authority in the preparation of a conference presentation and paper.

As it happened the processed pings did not become available during the course of the contract, thus preventing the inversion and transmission loss comparisons. However the other work was performed, and a number of other tasks related to BREVER and its analysis engine, SWAMI, were performed. These included verifying the consistency and accuracy of inversion results, enhancing the operation of BREVER, and performing some initial work to SWAMI that would allow the use of the program Bellhop, which produces eigenray-based environments, to replace the normal mode program PMODES.

14. **KEYWORDS, DESCRIPTORS or IDENTIFIERS** (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

Underwater Acoustics  
Geoacoustic Inversion  
Active Sonar  
Towed Arrays

This page intentionally left blank.

## **Defence R&D Canada**

Canada's leader in defence  
and National Security  
Science and Technology

## **R & D pour la défense Canada**

Chef de file au Canada en matière  
de science et de technologie pour  
la défense et la sécurité nationale



[www.drdc-rddc.gc.ca](http://www.drdc-rddc.gc.ca)